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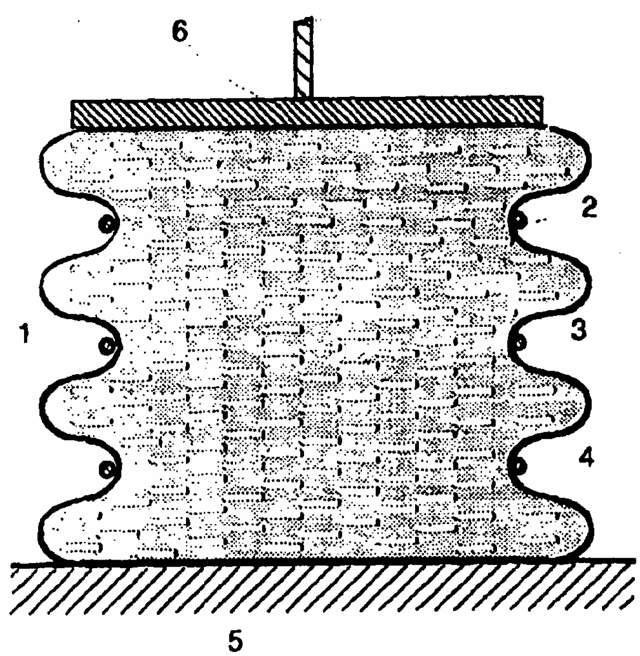
(54) Title: DEVICE INCORPORATING ELASTIC FLUIDS AND VISCOUS DAMPING

(57) Abstract

This invention relates to an improved shock-absorber device (6) comprising numerous small hollow flexible walled bodies which are preferably at least paritally gas-filled and are suspended in a liquid or gel medium and confined by a flexible walled vessel (1) or piston and cylinder arrangement. The device reduces the energy of impacts and also exploits the hydraulic properties of liquids to spread the force of an impact over a wider area. Many variations of the device of interest to travel, sports, medical, manufacturing and civil engineering industries are described. It offers a novel solution to the problem of exploding fuel tanks in aircraft and new methods of improving safety and comfort in motor vehicles. A "smart" active version of the device is also proposed.



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Device incorporating elastic fluids and viscous damping

Technical Field

This invention relates to improvements in elastic materials which offer viscous damping as used as shock absorbers to neutralise the undesirable effects of impact forces or vibrations on bodies or machinery.

According to the present invention there is provided a device for absorbing the unwanted energy of impulses or vibrations consisting of a moveable walled vessel or bladder enclosing an elastic material which exhibits viscous damping properties, the material comprising a plurality of capsules made from resilient material or including resilient materials and immersed in a liquid, grease or jelly medium so that when the pressure in the medium increases this pressure increase is hydraulically transmitted to the capsules causing a decrease in the volume of the resilient material and a spatial redistribution of the medium.

Background Art

The known method of absorbing the unwanted energy of impact forces or vibrations is to absorb it using combinations of springs and dashpots or their mathematical equivalents such as visco-elastic solids. The alternative to absorbing energy is to use a hydraulic means to dilute the pressure of an impact force by spreading it over a wide area of the body being protected. The inventive step described in this patent application is a device which can combine the energy dissipation benefits of spring-dashpot systems with the pressure reduction benefits of hydraulic systems.

A United Kingdom Patent Office Search and Advisory Service Search Report commissioned by the United Kingdom Department of Trade and Industry in relation to an application for government SMART funding has been obtained. (SAS reference Z7231, April 1996)

The subject of the search was:

> *"A shock-absorber comprising numerous small hollow flexible walled bodies which are at least partially gas-filled and are suspended in a liquid or gel medium confined by a flexible walled vessel."*

Only one document, a Japanese patent application JP 61051782A was considered to be possibly relevant. A subsequent translation of the document into English indicated that the device referred to in JP 61051782A was a visco-elastic solid with inclusive micro balls. This device did not offer the benefits of hydraulic pressure transmission through the medium and between capsules which are a feature of the present invention.

A key word search of the Compendex Engineering Index covering the period 1 January 1988 to 18 December 1996 has been carried out by the inventor. It has also failed to reveal any evidence of similar inventions being referred to in the 4 500 periodicals, reports, books and conference proceedings in the fields of engineering and technology covered by th index.

(Key words used for the search: vibration or impact or shock absorber or damping)

Discl sure of Invention

For this invention numerous small capsules, typically but not essentially of the order of millimetres or centimetres in size are suspended in a liquid, grease or jelly medium. The capsules can be made from solid resilient material but are preferably at least partially filled with gas. In the preferred case of gas filled capsules the capsule walls are flexible and/or have communication apertures so that changes in pressure within the medium lead to changes in pressure within the gas. The material is retained within a flexible walled vessel or bladder when it is being used for shock absorbing purposes. The flexible wall property can be realised by constructing the vessel from a soft material which deforms when it is subjected to external stresses or by using a piston and cylinder arrangement.

The preferred version of the device comprising the capsules, enclosed gas, the liquid, grease or jelly medium and movable walled vessel is analogous to a vehicle suspension system with the compression of the gas in the capsules being equivalent to the compression of the vehicle suspension springs and the damping resulting from the local change in the distribution of the medium replacing the function of a vehicle shock absorbing damper.

Typically, the bulk modulus of a liquid, grease or jelly is considerably higher than the bulk moduli of gases so if the pressure within the medium increases as a result of external applied forces then the volume of gas within the capsules is reduced and potential energy is stored within the capsules. This fraction of the work done on the material is reversible and allows the movable walled storage vessel to regain its original shape when the deforming forces have been removed. The reduction in the volume occupied by the gas causes local movement of the liquid/grease/jelly medium and the work done against the viscous forces within the medium is irreversibly lost as thermal energy.The viscous and elastic properties of the material can be altered as independent variables by changing the shape, number and size of the capsules.
It is also possible, by using suitably shaped capsules, to design the material so that it has dominantly elastic properties when subject to low magnitude forces, but viscous damping properties when subjected to large forces. This is useful for example in designing shock absorbing inserts for footwear.

Other shapes of capsules allow the viscous damping force to be maximised for low magnitude forces. This is of particular benefit when designing protective padding for sports or medical applications because it allows the pad to have a minimum possible thickness for a design specified level of shock absorption.

Trials have been carried out using water as the liquid medium but this is not the preferred liquid because of its low viscosity, propensity to leak if the bladder is ruptured and tendency to freeze at temperatures commonly experienced out of doors. Water with additives to depress its freezing point can be used but

better results have been obtained using synthetic oils, vegetable oils, hydraulic fluid, greases, syrups and petroleum jelly.
In principle any liquid, grease or jelly which allows the hydraulic transfer of pressure can be used as the medium. It is to be understood that the invention is not limited to the specific examples of media referred to in this patent application.
The liquid, grease or jelly chosen is a design variable and is selected after considering the application, health and safety and environmental requirements. For example a soft grease can be used if the device takes the form of a thin pad inserted in a garment or if leakage of the material following accidental puncturing of the retaining vessel poses a contamination problem. Petroleum jelly is the preferred medium in devices used in the food, pharmaceutical and confectionery industries. Liquids are preferred for applications where continuous shock or vibration absorption generates significant heat inside the device. Liquids with a high viscosity index can be used for applications where the temperature of the medium is expected to fluctuate significantly. Hydraulic fluid or synthetic oils may be used if contact with rubber is anticipated. Vegetable syrups similar to those used in the food and confectionery industries offer some of the combined benefits of petroleum jelly and liquids.
For the majority of applications where the generation of heat is not a problem petroleum jelly and multi-purpose automotive lubricating grease have been found to have a satisfactory combination of properties and in what follows the term jelly will be used for brevity when referring to high viscosity media.

For the purposes of this patent application, in the case of the preferred gas filled capsules, the term capsule will be used to describe any solid walled chamber used to contain the gas within the medium. The capsules may have rigid or flexible walls and the gas enclosed within them may be partitioned from the surrounding medium or in part have a common interface. The term material will be used in its broad sense to represent any form of matter but also specifically as a convenient shorthand for describing any combination of liquid, grease or jelly medium, solid capsules and/or gas filled capsules. The appropriate interpretation of the current use of the word material will be made clear from the adjacent text.

The device is compressible and also exhibits viscous damping properties but theoretical considerations and experimental evidence to date suggest that the device has the advantage over visco-elastic materials currently used as shock absorbers in that providing a suitable liquid medium is chosen it does not suffer from creep. Creep is the phenomenon whereby materials suffer a permanent change in physical dimensions as a result of the application of a continuous stress. By contrast, when liquids are used as the medium, the new material appears to make a full recovery to its original dimensions after deforming stresses have been removed. Absence of creep is a useful, but not essential feature of the device. Materials technologists will be aware of the propensity to creep of the various liquids, greases and jells which may be incorporated in the device. The title of this patent application has been provided as "Device incorporating elastic fluids and viscous damping" to indicate that it is covers both elastic and visco-elastic devices.

The material has a second advantage over existing solid visco-elastic shock absorbers. The fluid nature of the medium allows it to transmit pressur through the whole of the material inside the bladder, allowing the whole of the material to participate in the energy absorbing process. It can also cause an area of the protected surface underlying the bladder greater than the area of the impact zone to share in reacting to the residual force which is transmitted through the bladder. By contrast a visco-elastic solid concentrates the residual force on the area directly underlying the impact zone.

The medium, capsules and and containment chamber may all be treated with fire retardant additives in order to reduce fire hazards.

Brief Description of Drawings

Figures la and 1b are schematic diagrams of an elastic material according to the present invention.

Figures 2a to 15 show alternative embodiments of capsules that form part of the present invention.

Figure 16 is a sketch graph showing the approximate relationship between the deforming force and material thickness as a sample of the material is deformed.

Figure 17 shows a partitioned version of the elastic material.

Figures 18, 19 and 20 show alternative methods of preventing the capsules from clumping together.

Figures 21, 22 and 23 show methods of casting the vessel with some at least of the capsules being formed in the same mould as the vessel walls.

Figures 24, 25 and 26 show versions of the invention used as suspension units.

Figure 27 is a schematic diagram of an elastic material according to the present invention which incorporates a range of sizes of capsules.

Figure 28 shows an embodiment of the invention used for constrained layer damping.

Figure 29 shows an embodiment of the invention which can also be used to absorb exceptionally large impulse forces by crumpling and deforming permanently.

Figure 30 is a schematic diagram showing an active version of the invention which offers variable damping features when connected to a suitable electronic circuit.

Specific embodiments of the invention will now be described by way of example

Figures la and 1b are schematic diagrams of an elastic material according to the present invention. In figure 1a the circles such as 1 represent the capsules. In this example the capsules are elastic spherical shells totally enclosing the gas component of the material. Low cost examples of this type of capsule include expanded polystyrene beads. Higher cost versions of the hollow capsules can be made from a suitable elastomer with the shells offering viscous and elastic damping in their own right in addition to the novel form of damping which will now be described. 2 is the liquid/jelly/grease medium. These diagrams only show part of the material and the enclosing flexible walled vessel has been excluded. If external compressive forces are applied then the pressure throughout the region shown in the diagram is increased. The medium is virtually incompressible but the gas inside the elastic walled capsules obeys

Boyle's law (assuming isothermal conditions) and is reduced in volume. Pressure at any point in the medium is the same in all directions so the capsules retain their spherical shape after compression. Figure 1b shows the original region after compression with the reduction in volume, for all practical purposes, being the result of shrinkage in the size of the capsules. The additional potential energy stored in the capsules by virtue of their being compressed is released when the external forces are removed and is used to restore the capsules to their original size.

The change in size and also translational movement of the capsules when compressive forces are applied causes rearrangement of the medium. The medium has a high viscosity and work must be done against the viscous forces to produce the rearrangement. This work reappears as heat and the material increases in temperature slightly. The non-reversible component of the work done on the material is advantageous because it damps the oscillations of the material and eliminates whiplash effects.

If the material is used for example as a shock absorbing elbow pad in an article of sports wear then the capsules can move relative to each other allowing articulation of the elbow. If however the wearer falls causing an impact force on the elbow pad then the viscosity of the medium prevents the rapid migration of the capsules away from the area of action of the force on the pad so the pad largely retains its original thickness. Grease or petroleum jelly are the preferred medium for devices in garments because they have solid characteristics at low shear and do not slosh around when the wearer moves. They have a thixotropic nature with a low yield point and act as a hydraulic liquid under impact when the wearer falls.

gas filled

The gas filled capsules could be replaced by capsules which are not gas filled but are made from resilient material. The advantages of using gas filled capsules include a reduction in the mean density of the material, a reduction in stiffness constant and an increase in viscous damping due to the relatively large change in size of the capsules for a given deforming stress.

Figure 2a shows a modified version of a spherical capsule on a larger scale. In this version the capsule has an aperture,1 with a tube extending into the interior of the sphere so that the gas is in immediate contact with the medium. Figure 2b shows the same capsule when compressive forces are applied to the material. The medium is forced into the tube and work is done against viscous forces as the medium moves up. By altering the diameter of the tube the magnitude of the viscous force can be changed. This design offers a greater degree of control of the viscous damping forces compared with the first version of the invention. Those familiar with Poiseuille's formula for the flow of liquids through narrow tubes will be aware that the rate of flow of medium along the tube depends inversely on the viscosity coefficient but on the radius of the tube raised to the fourth power. This means that in designing a material to have a specified viscous damping effect changing the radius of the tube has a more radical effect than changing the viscosity of the jelly or liquid medium. For example, doubling the viscosity of the preferred jelly (liquid) reduces the rate of flow of the jelly (liquid) by a factor of two but decreasing the diameter of the tube by a factor of two decreases the rate of flow by a factor of sixteen.

In order to avoid the use of cumbersome language in this patent application the gas will generally be spoken of as being at the same pressur as the medium when in the relaxed equilibrium state. This is not strictly true because the effects of surface tension cause the liquid or jelly which enters th tube to have a curved meniscus. Typically, for a liquid with a concave meniscus this will cause capillary rise into the tube, with an increase in pressure inside the tube.Those with an expert knowledge of fluid mechanics will be aware that changes in the volumes of spherical gas capsules relates to the bulk viscosity of the surrounding liquid and movements of liquids down tubes relates to the shear viscosity. Both types of viscosity cause viscous damping so to avoid pedantic language the term viscosity will be used as a shorthand to represent both phenomenon.

This design of capsule requires that the chosen gas and jelly (or liquid) do not react chemically and that the gas does not dissolve in the medium. Suitable stable combinations are known to technologists with a knowledge of the properties of materials.

One disadvantage of this design is that if the impact forces are large then the medium will overshoot the end of the tube and be retained inside the capsule.

Figures 3a and 3b show a version of the spherical capsule with the tube sealed at the end so that the capsule has two gas storage volumes, one in contact with the medium, the other permanently trapped inside the interior of the capsule. Figure 3a shows a typical capsule before external impulse forces are applied, figure 3b shows the capsule with some medium inside the tube when an impulse force is at its peak value. If the capsule has elastic outer walls the diameter of the capsule would also be reduced in figure 3b.

Figures 4a and 4b show a spherical capsule with the sealed end of the tube expanded inside the capsule to create a larger space for occupation by gas in contact with the medium. In figure 4b the medium has been forced into the cavity but on removal of the external forces the medium retreats from the cavity.

In this example of capsule design there is a gradual increase in the surface area of the medium after it has broken free of the narrow confines of the tube. By contrast there is a sudden, discontinuous increase in surface area of the medium after the medium has broken free of the ends of the tube using the designs shown in figures 2. A consideration of the free surface energy in both cases indicates that the design shown in figures 4 is far less likely to lead to the depositing of medium inside the capsule.

Figure 5a shows a different shape of capsule, being a uniform bore hollow tube,1 sealed at end 2. Figure 5b shows the same capsule at a time of localised increase in pressure with medium, 1 being forced into the open end, 2 of the capsule.

Figure 6 shows a uniform hollow tube 1 nipped together half way along its length thus producing two capsules joined together, having similar properties to the capsules in figures 5.

Figure 7a shows uniform hollow tube capsule which is open to the surrounding medium at both ends. When the local pressure increases the medium moves in at both ends of the capsule. The design is stable and works without leakage of the gas if narrow diameter tubes are used. This is a simple design of capsule which can be mass produced very cheaply.

Figure 8 shows a hollow tube capsule as in figures 7 but bent to create an open toroid.

Figures 9, 10 and 11 show variations on the single open ended tube capsule design. In each of these designs the diameter of the tube decreases towards its closed end. A consequence of these designs is that the fraction of the shock absorbing mechanism which is attributed to viscous damping increases as the magnitude of the forces compressing the gas increases. This design could be used for example to form a shock absorbing pad in the heel of a sports or orthopaedic shoe. When walking or running on soft ground such as turf the impact forces would be relatively small and the shock absorption effect would be mainly elastic giving the shoe a degree of spring. For larger impact forces, for example those experienced when running on pavements, the additional shock absorbing effect would include an increased fraction of viscous damping which would be advantageous in preventing repetitive stress injuries.

Figures 12, 13 and 14 show the double open ended equivalents of the three previous designs.

Figure 15 shows a hollow capsule with an extended relatively narrow diameter aperture extending into the medium. This design has the reverse of the viscous and elastic properties shown in the six previous diagrams. For small impact forces where the medium is only driven further down the narrow extended tube without entering the larger cavity the dominant form of damping is viscous. For larger impact forces the dominant form of damping is elastic. This design of capsule is particularly useful when the material is used as padding in clothing for protection against occasional, massive, potentially bone fracturing impacts because it allows the desired degree of impact protection to be achieved for a minimum thickness of material.

This minimum thickness design feature can be explained by reference to the sketch graphs shown in figure 16.

These sketch graphs indicate the approximate relationship between the deforming forces and material thickness as a sample of the material including capsules similar to that shown in figure 15 is compressed. The step shaped graph, 1 shows the component of the applied compressive force which is required to overcome viscous drag and compress the material from an initial thickness t_i to a final thickness t_f. The curved graph, 2 shows the component of the applied force required to compress the gas inside the

capsule. The reversibl work done against th elastic forces must exceed the irreversible work done against the viscous drag, otherwise the pad will not return to its original thickness after the deforming force has been removed.

Graph 3 is the resultant force made up of components shown in graphs 1 and 2. F_{max} is a design specified maximum force which can be tolerated by the wearer without incurring pain or injury. The function of the padding is to absorb a design specified maximum kinetic energy after a fall without exceeding F_{max}. The kinetic energy absorbed by the padding in this example can be calculated from the area between graph 3 and the x axis.

Pads including material which is based on capsules of this design are only suitable for use as a protection against occasional impacts because they have a long recovery time. This is because after the deforming force has been removed the gas inside the capsule remains at a higher pressure than the surrounding medium. Further work needs to be done against the viscous drag when driving the medium out of the tube to achieve pressure equality. This can only be done slowly with thermal energy being transferred from the medium to the gas.

If the novel padding was replaced by a simple foam padding which relied solely on elastic compression to absorb the kinetic energy of an impact then the deforming force graph for a sample of the material which met the same force and energy criteria as graph 3 would be graph 4. Inspection of graph 4 indicates that the unstressed thickness of material required is considerably in excess of t_i.The novel material is a more effective energy absorber for a given thickness of material because of the additional work done against the external forces at the early stages of compression.These sketch graphs indicate that the new shock absorbing material offers considerable cosmetic and comfort benefits compared with the use of basic foam padding when designing impact protection body wear. Using a pre-stressed elastic shock absorber does not invalidate the above argument.

If the capsules and medium are blended by the manufacturer at normal atmospheric pressure and the finished product is subsequently used in a low pressure environment, for example at a high altitude location, then there is a possibility that some of the gas trapped inside the capsules will form bubbles of sufficiently large diameter that they can permanently break free from the capsule, eventually creating an unwanted pocket of gas inside the enclosing bladder. This problem can be overcome by blending the component parts of the material in a sealed vat at a pressure at least as low as the lowest expected working pressure and leaving the material to stabilise at low pressure before packing in its outer bladder.

For versions of the invention which require a flexible walled bladder the bladder must be shaped so that the anticipated deforming forces produce a reduction in volume. For example if the bladder takes the form of a mathematical prism with an ellipse shaped cross section then an impact along the major axis of the pad will tend to increase the interior volume, which is undesirable but an impact at right angles to the major axis will be effective in compressing the material. Simple shapes of bladders which are effective include

spherical, cylindrical, segments of spheres and segments of cylinders. In general to assist in mathematical modeling of novel design shapes of the invention simple mathematical shapes of the bladder are preferred but not essential.

If the bladder is large and the material is constantly flexed or subjected to deforming forces then there will be a tendency for the capsules to gather in clumps if the ratio of total volume of capsules to total volume of medium is low. This problem can be overcome by splitting the bladder into smaller compartments. A number of different designs of compartments are used to prevent clumping of insulating material in sleeping bags and similar designs can be used for the present invention. Clumping is not a problem if the proportions of capsules to medium is limited by close packing of capsules with a minimum of medium filling the remaining void space. A second, associated problem can still occur if large bladders are used to absorb impact forces which only act over a fraction of the surface area of the bladder at right angles to the direction of the force. In this case local thinning of the thickness of the bladder may simply be compensated for by bulging of the bladder elsewhere. The bulging problem can be solved in several ways using existing technology including the use of ties or flexible cross members which link together local, internal opposite faces of the bladder at intervals over the interior. These ties or flexible cross members have sufficiently high tensile strength and stiffness constants such that they do not break or stretch significantly when the device is in operation. However they are sufficiently flexible that they do not impede local thinning under the action of external forces. An alternative to the use of cross ties, suitable for thin pads of the device is to spot weld, rivet or otherwise permanently join opposite internal faces of the bladder together at intervals.

Figure 17 shows a bladder,1 enclosing a sample of the material. In this example the material is temporarily partitioned in two by a spring loaded clip, 2 and an end clamp, 3. Adjustable partitioning is an alternative way of limiting local bulging of the bladder and allows the end user to adjust and tune the device to their own preferences.

An alternative method of overcoming the bunching up problem is to bond the capsules permanently to a base material. Figure 18 shows tubular capsules including 1 bonded to a long flexible fibre,2. Figure 19 shows a variation on figure 18 with the columns of bonded capsules also being bonded by horizontal fibres such as 1, 2 and 3.

A version of the device using the arrangement shown in figure 19 may be used as an improved storage tank for the transportation of fuels and other liquids. By way of an example the invention may be used as a fuel tank for storing fuel in aircraft. Changes in the velocity of the aircraft cause the fuel to slosh around inside the storage tank. An existing solution to this problem is to include baffles inside the tank. If the baffles are replaced by matrixes of hollow tubes as shown in figure 19, with the hollow tubes being any of the shapes as described in this patent application then the efficiency with which the energy of sloshing

modes of vibration are absorbed will be significantly increased. In this example the storage tank would be a flexible walled bladder and the liquid medium would be the fuel. The storage bladder plus an auxiliary bladder, initially empty or filled with a small volume of air or other gas could be retained inside a fixed volume enclosure such as a wing. As fuel is pumped out of the storage bladder a mechanism would inflate the auxiliary bladder such that the total volume of the fuel storage bladder plus auxiliary bladder always filled the fixed volume. In addition to reducing fuel sloshing this design would also offer several other important safety features:

1 The fuel storage bladder would be able to absorb energy from shock waves passing through the fuel tank. Shock waves generated by bullets fired at the aircraft or shrapnel from bombs placed inside the aircraft by terrorists for example have been known to rupture fuel tanks with catastrophic consequences.

2 The fuel tanks would be less inclined to burst open during bumpy emergency landings. A unique feature of this version of the device is that the fuel acts as part of the shock absorbing system, protecting the integrity of its container.

3 The controlled expansion of the auxiliary bladder could be used to pump the liquid out of the fuel filled bladder. This would be a useful safety feature because it would eliminate the potential hazard of short circuits in the electrical system of the fuel pump causing ignition of the fuel or fuel vapour.

4 The expansion of the auxiliary bladder would progressively reduce the volume of the fuel filled bladder so that large volumes of potentially explosive fuel vapour were not retained inside the fuel tank.

5 By placing the auxiliary bladder between the fuel filled bladder and adjacent parts of the aircraft which are prone to reach high temperatures, for example air conditioning systems or engines the auxiliary bladder will act as a form of insulation reducing the likelihood of the stored fuel overheating.

Figure 20 is a side cross section of a different arrangement showing two layers of closed gas filled capsules 1 and 2 with each layer being bonded to flexible base sheets 3 and 4 and being immersed in a medium, 5. The capsules and base sheets are analogous to a material commonly known as bubble packing, with the exception that in the case of the present invention the capsules are preferably made from a more robust and resilient material and the capsules are of a pre-determined size, as required for a particular application.

Figure 21 is a side view cross section of a version of the invention which is a wedge inserted into the heel of a shoe or boot at the manufacturing stage. The flexible vessel is made from synthetic rubber, flexible

plastic or other gas tight material of a durable nature, suitable for use in footwear. Those with a technical knowledge of modern footwear design will be aware of the choic of materials availabl . The wedge is moulded in two parts, an upper and lower part, 1 and 2 which are joined together after being released from the moulds.The capsules of which 3 and 4 are examples are formed in the same manufacturers moulds as the walls of the wedge but are only joined to the internal walls by thin fibres so that they are essentially exposed to hydraulic pressure on all sides with the space between the capsules being filled with the jelly or liquid medium as for the versions of the invention described above. The capsules are preferably, but not exclusively, tuned to provide largely elastic rebound for low impact foot placements with increasing viscous damping for more violent foot placements as described earlier with reference to figures 9 to 14 inclusive.

Figures 22 and 23 show a variation on this design. Figure 22 is a side cross section of a heel wedge and figure 23 is a plan view of a cross section through the middle of the thickness of the same wedge. The capsules are moulded in the same moulds as the walls of the vessel and preferably the wedge is cast or moulded in two halves; 1 and 2 in figure 22. Before the two halves are joined together the component parts of the capsules, 3 and 4 in figure 22 are open, exposing their interior but form completed capsules after permanently bonding the upper and lower halves of the vessel and inclusive capsules together. One advantage of this method of construction is that the shape of the capsules is conveniently and accurately moulded to provide the desired combination of viscous and elastic properties.

Any of the variations of the device especially those illustrated in figures 21, 22 and 23 may be modified to create nested versions of the material, with a plurality of small capsules being enclosed within larger capsules. For example the capsules illustrated in figures 22 and 23 could each enclose a plurality of small gas enclosing spheres with the aperture of each larger capsule possibly including a grid which allowed the free movement of the medium but prevented the smaller capsules leaving the mouth of the larger capsule. The advantage of this nested design is that even if after prolonged use the inner walls of the larger capsules became contaminated by being permanently coated with the medium the device would still offer a useful degree of shock-absorbing benefits.

In addition to foot wear the device can be used to reduce the injuring effects of collisions or falls by adding pads of the material to a wide range of orthopaedic and sports wear. By way of example such pads could be included in the elbows of long sleeved shirts or sweaters, as pads in undergarments or other leg wear to protect the knees, hips and shins, as padding in helmets, gloves, including boxing gloves and mittens.

In particular, bladders of the material can be used as hip protection pads to protect the neck of the hip bones of Osteoporosis sufferers. For comfort and flexibility the hip pad preferably consists of a plurality of vertical, elongated, side by side, slightly overlapping pads attached to a strip of material at their upper nds and free to move independently at their lower ends. A second layer of slightly overlapping

horizontal pads loosely connected to each other so that they ar free to move relative to each other when the wearer moves may also be added for extra cushioning. The design of the hip pad could be improved by constructing a segmented pad with the segments which lie directly over the neck of the Femur having a lower stiffness constant than the segments which overlie the surrounding soft tissue. This would have a beneficial effect in shunting a fraction of the force of a direct sideways fall on to the soft tissue above and to the sides of the Femur, with the high stiffness material and the underlying soft tissue acting as two shock absorbers in series.

The unique properties of the material can be exploited to improve the design of physiotherapy and exercise equipment. For example a hand grip improver can be made from a sausage shaped bladder approximately 4 centimetres in diameter filled with the material. When the bladder is squeezed the hydraulic nature of the material will spread the pressure uniformly over the fingers and palm. On releasing the grip the viscous damping will retard the rate of reformation of the bladder and eliminate spring-back injuries to the hand.

Figure 24 shows the material in a containing vessel, 1 with flexible corrugated sides which are reinforced by external concentric metal rings 2, 3 and 4. Alternatively the separate rings may be replaced by a single helical coil of wire. The vessel rests on a firm surface, 5 and the material is used to cushion vibrations or impulses transmitted to the material via a piston, 6. This arrangement may be used as a shock absorbing system to isolate a piece of machinery from the ground. For example to prevent transmission of vibrations from a vibrating machine or prevent external vibrations affecting a delicate piece of machinery.

Engineers will be aware that unwanted standing waves can be set up in helical coil springs when they are subjected to periodic excitations. An advantage of the present invention, as shown in figure 24 is that if a helical spring is used for reinforcement and also has sufficient stiffness that it supports a significant fraction of the load then the standing wave problem is minimised because of the damping effect offered by the intimate contact between the vessel walls and the coils of the spring.

If the shock- absorber is used for extended periods of continuous duty then the none conservative work done on the material will result in an increase in suspension system temperature. The heat generated can be conducted to the containment chamber walls if the liquid/jelly medium has good thermal conductivity properties. Liquids are preferably used for this type of application but if the design requires the use of grease or jelly then the thermal conductivity of the medium can be improved by adding particles of copper, graphite or other good thermal conductors to the medium. In addition the gas capsules may be chosen to have good thermal conduction properties.

A range of designs of air springs similar but not identical in shape to the vessel shown in figure 24 are in common use. In som of these designs fibres of steel or other suitable materials are incorporated into the

walls of the air retaining vessel in order to provide reinforcement. These known designs may be used as alternatives to the vessel shown in figure 24 with the air inside the vessel being replaced by any f the material compositions described in this patent application.

Figure 25 is a cross section of a two chamber variation of the invention. The horizontal H shaped outer part, 1 is a rigid vessel made from metal, robust plastic or other material which will not change shape appreciably when subjected to normal working pressures. The outer vessel is similar in appearance to a large bobbin or reel with the upper and lower parts being wide diameter, hollow cylinders 2 and 3 connected via a long, relatively narrow cylinder, 4. 5 is a sliding fit piston with a piston shaft 6 which partitions the vessel into two isolated volumes, above and below the piston. 7 is a sliding fit sealing bearing which prevents leakage of the medium. The vessel rests on a firm surface and the impacts are transmitted to the material via the piston. On the down stroke the novel material below the piston is compressed and the material above the piston expands. The process is reversed on the up-stroke.

The device will only function in a satisfactory manner if it rests on a firm surface, 8. If the device is used as a novel form of vehicle suspension with say the shaft, 6 connected to a road wheel and 8 being part of the body of the vehicle then 8 can no longer be considered as a firm surface because of the finite weight of the vehicle. For use as part of a vehicle suspension system the material is preferably re-tuned so that it is lightly damped as the piston moves deeper into the vessel, away from bearing 7 and is heavily damped as the piston moves back towards 7. It is possible to re-engineer the designs of capsules described above so that they include one way valves which offer a wide aperture with low viscous drag to medium entering the capsules but high viscous drag to medium leaving the capsules.

A simpler method of achieving different rates of damping on the up and down strokes is to use a container with the wider diameter cylinders 2 and 3 having different volumes to each other and different blends of material above and below the piston. Likewise a two chamber version of the device shown in figure 24 can be constructed to offer similar ride improvement benefits.

A third method of modifying the device for use as part of a vehicle suspension system is shown in figure 26.

Figure 26 shows a modification of the device as previously illustrated in figure 25. The piston has been modified by the addition of two sets of one way valves to its crown. The first set represented by 1 are wide clearance valves which allow the easy flow of the liquid or jelly medium from the lower chamber to the upper chamber on the down stroke. The second set of valves represented by 2 are narrower clearance valves which allow the reverse flow of medium material from the upper to the lower chamber on the up stroke but with increased viscous drag.

3 and 4 are mesh grills which keep the capsules clear of the path of the piston and prevent them from clogging up the vicinity of the valves. For this version of the device where the viscous drag is created mainly by th passage of liquid or jelly through the piston the capsules can take the form of simple elastic spheres as illustrated in figures 1.

A similar effect could be created by adding valves and by-pass lines between the two chambers, instead of adding the valves to the piston crown.

Materials technologists will be aware that hollow resilient spheres of the order of a micron in diameter are commercially available. These may be used as at least as some of the capsules for versions of the invention which involve valves. They have the advantage that they are sufficiently small to pass through the valves. By using flap valves with soft faces for example damage to the microspheres can be prevented when the valves are closed.

For applications of the invention where the material is stressed to a considerably higher pressure than atmospheric pressure throughout its working life, for example in vehicle suspension systems, the material may be blended by the manufacturer inside a sealed vat operating at an excess pressure comparable with the anticipated mean working pressure

Several applications of the invention are specific to the transport industries. Pads of the shock absorbing material may be used to cover hard, protruding surfaces and edges in motor vehicles, trains, aircraft and boats. In particular the invention may take the form of a pad which is used to cushion the rim of a steering wheel. Car bumpers and other bodywork protections such as bull bars may incorporate pads of the material to reduce the damage caused by low speed collisions and to reduce the injuries suffered by pedestrians who are hit by the vehicle. Fenders on boats may also include large pads of the material.

Fatigue, discomfort and even injury are often caused to passengers as a result of vibrations passing through the vehicle bodywork into the passengers bodies. These problems are particularly acute in industrial vehicles such as tractors and fork lift trucks. These vibrations can be reduced by separating the points of contact of the passenger with the body of the vehicle with pads of the material. Foot-well pads and small pads on the foot control pedals can be used to reduce vibrations through the legs and pads can be incorporated in the seats to reduce vibrations to the trunk of the body. Pads incorporated into the backs and head-rests of seats will also be beneficial in reducing back and neck injuries in rear shunting accidents.

Beds on boats, trains and airplanes will also be improved by adding mattresses or under-pads of the material. In instances where large areas of th human body are in contact with pads of the device for prolonged periods of time a problem of localised build up of un-vaporised sweat may occur. Those with an

appropriate expert knowledge will be able to solve such problems using existing technology, for example by using intermediate moisture absorbing pads or intermediate ventilated pads between the device and the body.

Other transport applications include the incorporation of the material into road humps or sleeping policemen in order to slow down vehicles without causing damage to the vehicle suspension or discomfort for the passengers. Aircraft carriers can include large pads of the material which can be uncovered on their decks to retard the motion of landing aircraft.

The device has a low mass making it attractive for space applications including the suppression of spacecraft equipment induced structural vibrations which tend to cause jitter of telescopes and other sensitive on-board equipment. Versions of the device in the shape of large O rings may act as buffers to facilitate the docking of modules in space and also assist in sealing the interfaces between docked spacecraft.

Saddles on horses may incorporate an under pad of the material to reduce the damaging effects of vibrations on the horses spine and muscles caused by carrying a rider or load.

Shock absorbing pads of the material may be incorporated into the hand grips of sports equipment and tools. Such pads would be particularly useful in solving the problem of white fingers (a peripheral circulatory disturbance) by reducing the vibrations transmitted to the users hands by vibrating power tools. One advantage of using the present invention instead of existing visco-elastic solid hand grips is that the device can mould itself to fit the grip of the users hand.

Pads of the device may be used in the construction of buildings and structures which are threatened by unwanted vibrations such as earthquakes, local heavy traffic movements or wind induced vibrations. The material may be incorporated into hollow beams to damp vibrations of and/or through the beams with the walls of the beams acting as the flexible walled material retaining vessel.

Domestic uses include using pads of the material in domestic articles which produce unwanted vibrations. These include washing machines and high fidelity audio equipment. The absorption spectrum of a pad of the material varies with its composition. In situations where the pad is called upon to absorb a wide range of unwanted frequencies such as the audio equipment example it may be advantageous to use a composite pad consisting of two pads having different compositions in series or use a pad of the material in series with a plurality of sheets of visco-elastic polymers. Alternatively, the bladder which is used to retain the material may be composed of a visco-elastic polymer which has a complimentary absorption spectrum to the material.

If a number of uniform sized spheres ar stored together in a container and allowed to settle into their most stable arrangement so that they occupy the minimum possible volume then their arrangement is is commonly referred to as a close packing arrangement. In the close packing arrangement the spheres occupy 74% of the available space. With reference to the present invention this means that if the material consists of uniform sized gas filled spheres surrounded by liquid then the maximum ratio of volume of spheres to volume of liquid is 74:26. This ratio can be increased in favour of the volume of the spheres if a second set of smaller uniform sized gas filled spheres is introduced which are selected so that they just fit into the voids between the larger spheres without prising the larger spheres apart. This process of void filling can be repeated using successively smaller gas filled spheres to a lower limit of size which is only limited by the size of gas filled spheres commercially available. Currently the smallest gas filled spheres available are of the order of microns in diameter.

Figure 27 shows an arrangement of gas filled spheres with 1, 2 and 3 being successively smaller sized spheres with can rest in close contact while still allowing close packing of the largest size of spheres shown. In order to ensure that all of the spheres participate effectively in the reversible energy absorbing process is advantageous that successively smaller spheres are constructed with progressively thinner walls or are constructed from different materials which have progressively smaller elastic constants. One method of preparing this version of the material would be to blend the different sizes of spheres together in an evacuated chamber so that no air gaps existed between the spheres, add sufficient liquid on top of the blend to fill the remaining voids and then introduce air into the chamber above the liquid such that the air pressure forced the liquid into the voids.

Constrained layer damping is a common industrial technique for damping vibrations in panels or components constructed from metals or other materials which have low natural internal damping. A constrained layer material has a sandwich construction with two parts of the component or two layers of the panel being separated by a visco-elastic material such as bitumen or synthetic rubber. The present material may also be used for constrained layer damping but is preferably used with the sandwich structure modified so that movements of the gas filled capsules is localised. Figure 28 shows a novel version of a constrained layer sandwich. 1 and 2 are layers of a component which is damped by a sandwiched layer of the new material. The new material in this example consists of a mono-layer of uniform sized gas filled spheres such as 3 separated from the layers of the component and from each other by liquid. The facing layers of the component are shaped with hemispherical hollows which retain the spheres. Alternatively, if it is desirable that the the material should be able to flex along an arc with an axis out of the page then the hemispherical hollows can be replaced by semicircular channels out of the page. Layers 1 and 2 define the moveable walls of the container and the perimeter of the sandwich layer is sealed by a gasket, not shown, to complete the vessel.

Bumper

The bumpers of modern vehicles are commonly attached to the body of the vehicle by lengths of crumple zon material which are deliberately designed to crumpl and absorb the energy of low speed impacts without the rearwards body of the vehicle being damaged. The repair job on the vehicle following such a collision then consists of simply replacing the crumple zone material. The cost and frequency of repairs can be further reduced if a composite material consisting of a sandwich of two rigid materials and a layer of the new material is used.

Figure 29 shows an example of a novel design of crumple zone material which is a version of the device. The middle layer of the sandwich is similar to that shown in figure 28 but the outer layers 1 and 2 are made from steel, aluminium or other rigid material chosen so that the rigid material deforms and absorbs energy in preference to damaging the body to the rear of the crumple zone. Gentle impacts do not even damage the two rigid layers but have their impact energy absorbed by the device.

A similar composite material could be used to protect the human body from impacts. For example it could be used in shin pads for footballers.

Pads of the material may be used in combination with other materials to produce body armour which is effective against attack by knifes, sharp objects, bullets and other projectiles. By way of an example, according to the present invention, a bullet and/or stab-proof vest could consist of an outer layer of a woven carbon fibre material such as Kevlar (RTM) backed by a plurality of pads of the new material. The backing pads would serve several functions. They would allow damped motion of the woven material in the direction of the impact, resulting in deceleration of the projectile or weapon, reducing the stresses on the woven material and reducing the fraction of the kinetic energy of the projectile transferred to the wearers body. The liquid/jelly medium would help spread the residual impact force, reducing bruising to the wearer. The pad would also increase the separation distance between the material and the wearers body so if a knife for example partially penetrated the material its depth of penetration into the wearers body would be reduced.

The work done on the pad by the moving woven material in front of the projectile can be increased by increasing the area of the woven material that moves forward. This can be achieved for example by having an open mesh chain mail bonded to the woven material and placed between the material and the pad. This design benefit can be further enhanced by having a plurality of layers of chain mail behind the woven material, each layer having increasing link size.

The liquid used for the present invention may take the form of an electrorheological or magnetoelectrorheological fluid. Electrorheological fluids are suspensions of dielectric particles in insulating mediums which exhibit controllable rheological behaviour in the presence of applied electric fields. Their particles polarise and interparticle forces lead them to produce chains across the electrode gap, causing a considerabl increase in viscosity. Magnetoelectrorheological fluids typically include particles which have a ferromagnetic layer inside the electrorheologically active layer. These particles

produce chains and an increase in viscosity when they are immersed in a magnetic field. In addition to the known configurations of electrodes used to increase viscosity using these phenomenon the present invention may exploit these phenomenon in innovative ways. For example, dielectric gas capsules may take the part of the dielectric particles. The relatively large size of the gas capsules means that they would have large dipole moments. Alternatively, considering the arrangement shown in figure 28, layers 1 and 2 may be attached to high voltage power supplies of opposite polarity to provide an electric field across the gap between them. The spherical capsules, 3 may be coated in electrically conducting material so that induced charges of opposite polarities are created opposite 1 and 2.

Figure 30 shows an array of hollow tube gas capsules which have been modified to exploit the phenomenon of electrorheology. The tubes are made from insulating material but have electrically conducting outer layers. 1 is an electrical conductor which is in electrical contact with the first column of tubes. 2 and 3 are conductors in contact with the second and third columns of tubes. 4, 5, 6, 7 and 8 are separate conductors which are threaded horizontally through the rows of tubes. If for example positive high potentials can be applied to the vertical wires and negative high potentials applied to the horizontal wires then strong electric fields will be created inside the tubes. If the liquid is chosen to have electrorheological properties then the viscous damping due to movement of liquid inside the tubes is enhanced when the electrodes are active. Computer engineers familiar with the design of older computer memory stores will recognise the visual similarity between figure 30 and ferrite core memories. Using similar electronic systems to those used for writing binary digits in ferrite cores the field strength inside individual tubes can be altered, allowing the energy absorbing properties of individual tubes to be altered. Electrorheological viscosity changes can be achieved in less than one millisecond allowing for example the viscous damping provided by individual tubes to be different for the compression and recovery stages of operation. If the arrangement shown in figure 30 is used for constrained layer damping then the damping properties of different zones of a sheet of material can be actively changed provided that the active damping layer is split into partitions so that the flow of liquid and related damping is localised within the partition. Additional horizontal wires may be threaded through the tubes with the wires being coiled inside the tubes producing small solenoids. When a current passes through a solenoid the solenoid becomes a magnetic dipole. If the dielectric particles suspended in the liquid include ferromagnetic material then the particles will be attracted into the tubes. This migration would help to overcome the problem of separation of dielectric particles and support fluid which commonly occurs with existing electrorheological fluids. If the coils were made from suitable resistance wire then the gas within the tubes would be heated when a current flowed, increasing the stiffness constant of the capsule.

A novel type of electrorheological behaviour could be created by placing spherical gas capsules, as described in this patent application between electrically charged plates or grids. If the gas capsules are such that they have electrically conducting surfaces then capsules which come in contact with one of the electrodes would receive a charge and be repelled by the electrode. If the charged capsules are then subjected to impact forces which compress them the charge density on the surface of the capsules would increase. Some of the energy of the impact would be used up as work done in increasing the charge density.

Device inc rp rating elastic fluids and viscous damping

Claims

1 A device for absorbing the unwanted energy of impulses or vibrations consisting of a moveable walled vessel or bladder enclosing an elastic material which exhibits viscous damping properties, the material comprising a plurality of capsules made from resilient material or including resilient materials and immersed in a liquid, grease or jelly medium so that when the pressure in the medium increases this pressure increase is hydraulically transmitted to the capsules causing a decrease in the volume of the resilient material and a spatial redistribution of the medium.

2 A device according to claim 1 with some at least of the capsules being at least partially filled with gas with the gas retaining capsules having flexible walls and/or an aperture with access to the medium so that when the pressure in the medium increases this pressure increase is transmitted to the gas causing a reduction in the volume of the gas and a spatial redistribution of the medium.

3 A device according to any of the above claims with the liquid, grease or jelly medium being chosen so that its freezing point is several degrees below the freezing point of water at normal atmospheric pressure.

4 A device according to any of the above claims with the viscosity of the liquid, grease or jelly medium being in excess of the viscosity of water over the normal range of temperatures which a given sample of the device is designed to operate at.

5 A device according to any of the above claims with the medium being petroleum jelly optionally blended with known fillers or additives.

6 A device according to any of claims 1 to 4 with the medium being a lithium grease optionally blended with known fillers or additives.

7 A device according to any of the above claims with the capsules and medium being blended by the manufacturer and/or left to settle in a closed vat at a working pressure which is lower than the lowest intended operating pressure.

8 A device according to any of the above claims with some, at least, of the components of the device being treated with fire retardant chemicals.

9 A device according to any of the above claims with the capsules and/or medium being modified by the addition of thermally conducting ingredients in order to enhance the rate of dissipation of heat from the d vice during periods of continuous operation.

10 A device according to any of the above claims with the capsules specifically taking the shape of spheres with the maximum diameter of the spheres being less than or equal to the thickness of the material inside the bladder or flexible walled vessel.

11 A device according to any of the above claims with the capsules specifically taking the shape of spheres with at least some of the spheres having one or more apertures in their surface, allowing the liquid, grease or jelly medium to enter and partially fill the capsule when the pressure in the medium increases.

12 A device according to any of claims 2 to 11 with the capsules specifically taking the shape of spheres with at least some of the spheres having one or more apertures with tubes having mouths which fill the apertures extending into the interior of the same spheres and the tubes having a sufficiently narrow diameter that the gas trapped inside the tubes is in a stable low potential energy state and is not displaced by the medium.

13 A device according to claim 12 with the the tubes being sealed at their inner ends so that even at high working pressures the medium is prevented from travelling past the inner end of the tube and being deposited in the interior of the sphere.

14 A device according to any of claims 2 to 13 with the capsules specifically taking the shape of spheres with at least some of the spheres having tubes which lead to their interior with the inner ends of the tubes leading to chambers inside the spheres so that the total volume of gas trapped inside a sphere is partitioned into two volumes with one volume being permanently cut off from the medium and the second volume, in the inner chamber, being in contact with the a boundary of the medium at or inside the mouth of the tube.

15 A device according to any of claims 2 to 9 with at least some of the capsules taking the form of parallel sided tubes being sealed at one end and having a sufficiently narrow diameter that the gas trapped inside the tubes is in a stable low potential energy state and is not displaced by the medium.

16 A device according to any of claims 2 to 9 with at least some of the capsules taking the form of parallel sided tubes being open at each end but being constrained at or near their mid point so that each tube forms effectively two tubes having similar properties to the tubes in claim 15.

17 A device according to any of claims 2 to 9 with at least some of the capsules taking the form of parallel sided tubes being open at each end and having a sufficiently narrow diameter that the gas trapped inside the tubes is in a stable low potential energy state and is not displaced by the medium.

18 A device according to any of claims 15, 16 or 17 with at least some of the capsules taking the form of tubes having a uniform internal cross sectional area with the tubes being bent so that the principle axis along the centre of the tubes deviates from being a straight line.

19 A device according to any of claims 15, 16, 17 or 18 with at least some of the capsules taking form of tubes having a uniform internal cross sectional area with the tubes being bent so that they form open ended tori.

20 A device according to any of claims 2 to 9 with at least some of the capsules taking the form of tubes closed at one end with the diameter of the tubes gradually narrowing with the widest diameter being at the mouth of the tube, so that the viscous damping, as a fraction of the total damping, increases as the pressure within the medium increases.

21 A device according to claim 20 with the modification that a small chamber to increase the volume of gas stored inside the capsule is added at the closed end of the tube.

22 A device according to claims 20 or 21 but with the modification that the narrowing occurs as a series of steps rather than being a smooth variable.

23 A device according to claims 20, 21 or 22 but modified with the capsule having a plurality of tubes with open ends, each allowing direct contact between the gas and the medium.

24 A device according to any of claims 2 to 9 with at least some of the capsules taking the form of chambers with direct access to the surrounding medium via a tube which extends into the medium with the dimensions of the tube being such that at low excess pressures the medium driven into the capsule is subject mainly to viscous drag damping but as the excess pressure increases the viscous damping as a fraction of the total damping decreases.

25 A device according to any of the above claims with the capsules having a plurality of graded sizes such that the second largest size of capsules fit into the void space between the largest capsules when the largest capsules are close packed, the third largest capsules fit into the remaining void space and so forth for diminishing sizes of capsules.

26 A device according to claim 25 with the composition of the different size grades of capsule being different in order to ensure that the different sizes of capsules have approximately the same stiffness constant.

27 A device according to any of the above claims with the enclosing bladder being reversibly partitioned into segments by a movable clamp which prevents the transfer of capsules between the segments.

28 A device according to any of the above claims with the addition that the material is enclosed in a bladder shaped in its relaxed state such that an impact in the anticipated direction causes the shape of the bladder to change such that the volume of the bladder is reduced unless the surface area of the bladder increases elastically during the deforming process.

29 A device according to any of the above claims with the addition that the material is enclosed in a bladder shaped in its relaxed state in the shape of a sphere or segment of a sphere.

30 A device according to any of claims 1 to 28 with the addition that the material is enclosed in a bladder shaped in its relaxed state in the shape of a cylinder or segment of a cylinder.

31 A device according to any of the above claims with the shape of the bladder being locally constrained by linking internal opposite faces of the bladder by ties, flexible cross members or by locally permanently bonding opposite internal faces such that localised external forces on part of the bladder causing bulk movement of the material within the bladder do not cause unwanted bulking in other parts of the bladder.

32 A device according to any of the above claims with some at least of the capsules being linked together by a plurality of flexible fibres so that their relative movement is restricted.

33 A device according to any of the above claims with some at least of the capsules being bonded to sheets of flexible material.

34 A device according to any of the above claims with parts at least of some of the capsules and parts at least of the enclosing vessel being manufactured from the same mould, causing capsules to be permanently attached to the walls of the vessel but still being substantially surrounded by the medium so that the capsules are subject to hydraulically transmitted pressure changes in the medium.

35 A device according to claim 34 with the device taking the form of a wedge which is built into the heel and/or sole of a shoe or other form of footwear.

36 A device according to any of claims 1 to 34 with the device taking the form of a plurality of protective pads which are added to a helmet or other form of head wear or are otherwise attached to the wearers body for protecting the head of the wearer.

37 A device according to any of claims 1 to 34 with the device taking the form of a plurality of protective pads which are added to gloves, mittens or other form of clothing or are otherwise attached to the wearers body for protecting the hands of the wearer.

38 A device according to any of claims 1 to 34 with the device taking the form of a plurality of protective pads which are added to a jersey, jacket , underwear or other form of clothing or are otherwise attached to the wearers body for protecting the upper body of the wearer.

39 A device according to any of claims 1 to 34 with the device taking the form of a plurality of protective pads which are added to a pair of trousers, underwear or other form of clothing or are otherwise attached to the wearers body for protecting the lower body of the wearer.

40 A device according to any of claims 1 to 34 with the device taking the form of a pad or cushion which is attached to a vehicle bumper or other part of the vehicle, with the device being used to protect the body and/or contents of the vehicle.

41 A device according to any of claims 1 to 34 with the device taking the form of a pad which acts as a cover for a vehicle steering wheel to cushion the impact forces if the driver collides with the steering wheel during a collision.

42 A device according to any of claims 1 to 34 with the device taking the form of a pad which is used to cushion the underside of a saddle on an animals back.

43 A device according to any of claims 1 to 34 with the device taking the form of a hand-grip on a tool or other item of hand-held equipment.

44 A device according to any of claims 1 to 34 with the device taking the form of a pad to reduce the transmission of vibrations from the casing or interior of an item of high fidelity audio equipment or other vibration generating equipment to the surfaces with which it is in contact.

45 A device according to any of the above claims with the moveable walled outer vessel or bladder being reinforced by the addition of constraining bands or coils made from metal or other suitable strong, stiff, resilient material.

46 A device according to any of claims 1 to 26 with the outer vessel having a moveable wall which takes the form of a movable piston constrained to move by piston chamber walls.

47 A device according to claim 46 with the outer vessel having rigid walls and containing two material filled chambers separated by a piston with a piston shaft which is linked to the exterior of the vessel such that movement of the piston compresses the material in one of the chambers, reducing its volume and simultaneously causes a corresponding increase in volume of the second chamber.

48 A device according to claim 47 with the two chambers having different volumes when on standby duty and with the material in the two chambers offering different magnitudes of opposition forces to the movement of the piston when the piston moves such that the movement of the piston away from the neutral, standby position has different degrees of damping depending on the direction of piston movement.

49 A device according to claim 48 with the piston being modified by the addition of two sets of one way valves to the piston crown with the clearance or size of the sets of valves differing so that the viscous drag on the two opposite directions of travel of the piston differs.

50 A device according to claim 49 with differing sizes of by pass lines and one way valves being added which connect the two chambers so that the viscous drag on the two opposite directions of travel of the piston differs.

51 A device according to any of the above claims with the material being pre-stressed so that the pressure inside the gas and/or medium when the device is in the relaxed state is in excess of normal atmospheric pressure.

52 A device according to any of the above claims with some at least of the capsules being nested so that larger capsules enclose a plurality of smaller capsules.

53 A device according to any of the above claims with some at least of the capsules including one way valves which restrict the flow of the medium in or out of the capsule, depending on the direction allowed by the valve so that the material has different viscous and/or elastic properties on compression and expansion.

54 A device according to any of claims 1 to 34 or 45 to 53 with the device being incorporated into the construction of a building or other engineering structure in order to reduce the undesirable effects of earth tremors, wind or other induced vibrations on the structure.

55 A device according to any of claims 1 to 26 with the vessel retaining the material being a hollow beam.

56 A device according to any of claims 1 to 26 or 31 to 34 with the energy absorbing material forming a thin layer sandwiched between two parts of a component so that the device provides constrained layer damping.

57 A device according to claim 56 with at least one of the faces of the component in common with the constrained layer being pitted to restrain the transverse movement of the capsules.

58 A device according to any of the above claims with at least one of the walls of the containing vessel being shaped and made from a suitable material such that the wall crumples and absorbs some of the energy during high energy impacts.

59 A device according to any of claims 1 to 34 with the device taking the form of a plurality of pads combined with a Kevlar (RTM) or similar high strength woven material to form stab and/or bullet proof armour, with the woven material being placed on the far side of the pad, away from the wearers body with the pad being used to decelerate the motion of the weapon or projectile after it has made contact with the woven material.

60 A device according to claim 59 with a plurality of layers of chain mail being used to separate the woven material from the pad and with each layer of chain mail towards the direction of the pad having an increasing open size of weave.

61 A device according to any of the above claims with the medium being an electrorheological fluid and the necessary electrodes and other circuit components being added to the device, allowing the viscosity of the medium to be varied by varying the electric field strength across at least some parts of the fluid.

62 A device according to any of the above claims with the medium being an magnetoelectrorheological fluid and the necessary circuit components being added to the device, allowing the viscosity of the medium to be varied by varying the magnetic field strength across at least some parts of the fluid.

63 A device according to any of the above claims with at least some of the capsules being made from dielectric material so that they behave in a manner similar to the dielectric particles in an electrorheological fluid, allowing the capsules to form chains which discourage their relative movement when immersed in an electric field.

64 A device according to any of the above claims with at least some of the capsules incorporating ferromagnetic material so that they behave in a manner similar to magnetic dipoles allowing the capsules to form chains which discourage their relative movement when immersed in a magnetic field.

65 A device according to any of the above claims with at least some of the capsules incorporating or having their walls coated with electrically conducting materials and appropriate electrodes and other circuit elements being added to induce or deposit charges on the surface of the capsules such that work has to be done against the charges if the surface area of the capsules is reduced during impact.

66 A device according to any of the above claims with at least some of the capsules having at least one open interface between the gas and medium with these capsules having insulating walls coated externally with electrically conducting material with the outer wall of these capsules being connected to an electrode wire and a second central coaxial electrode being threaded through the capsules allowing an electric field to be set up inside the capsule for the purpose of exploiting electrorheological phenomenon as in claim 61.

67 A device according to claim 66 with the inclusion of electric circuits which allow the electric fields inside different capsules to be altered independently.

68 A device according to claim 66 with the enclosing vessel or bladder being partitioned into sections to prevent or minimise the flow of the medium between sections.

69 A device according to claim 66, 67 or 68 with at least some of the capsules including internal coaxial coils connected to external power supplies allowing the gas inside individual capsules to be heated to increase the gas pressure.

70 A device according to claim 66, 67, 68 or 69 with at least some of the capsules including internal coaxial coils connected to external power supplies allowing individual capsules to act as magnetic dipoles when a current passes through the coils causing magneto-electrorheological particles to align themselves along the magnetic field lines of the dipoles.

71 A device according to any of claims 1 to 34 with the liquid medium being a fuel or other liquid in transportation.

72 A device according to claim 71 with the liquid storing bladder and a second bladder being retained inside a fixed volume vessel with the second bladder being inflated at a controlled rate in order to apply pressure on the first bladder in order to prevent the build-up of vapour in the first bladder and/or to pump the liquid out of the first bladder when required.

73 A device according to any of claims 1 to 34 in the shape of a large O ring which acts as a buffer to facilitate the docking of vehicles, including modules in space and also assists in sealing the interfaces between docked vehicles.

74 A device substantially as described or illustrated in this patent application.

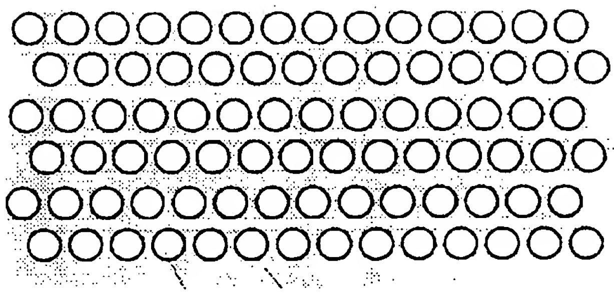


Fig 1a 1 2

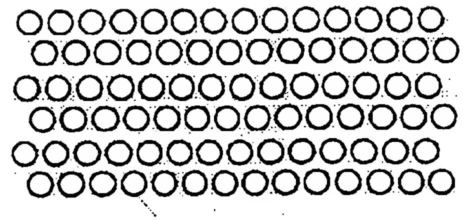


Fig 1b 1 2

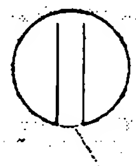


Fig 2a 1

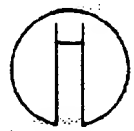


Fig 2b

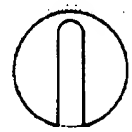


Fig 3a

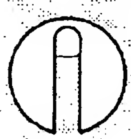


Fig 3b

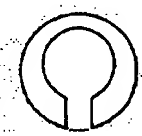


Fig 4a

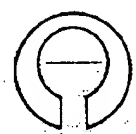


Fig 4b

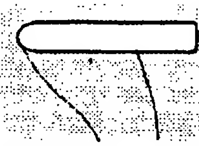


Fig 5a 2 1

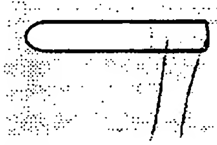
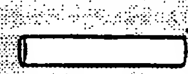


Fig 5b 1 2

Fig 6



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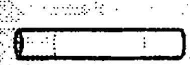


Fig 7b

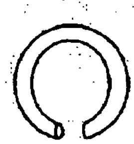
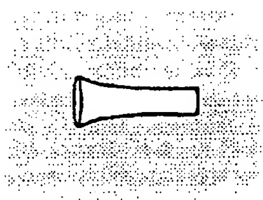


Fig 8



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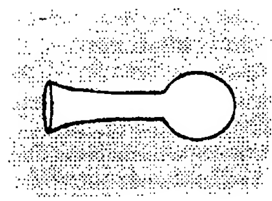


Fig 10

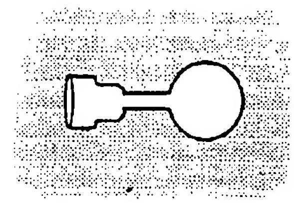
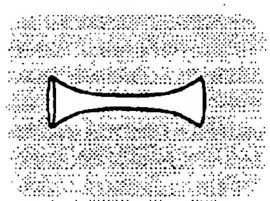


Fig 11



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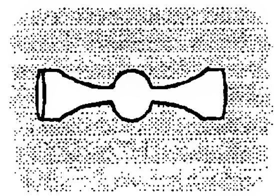

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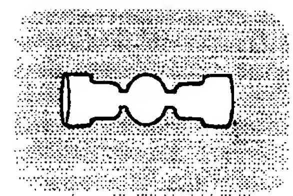

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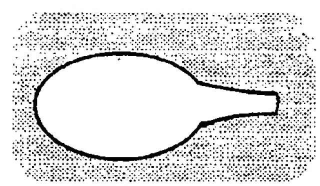

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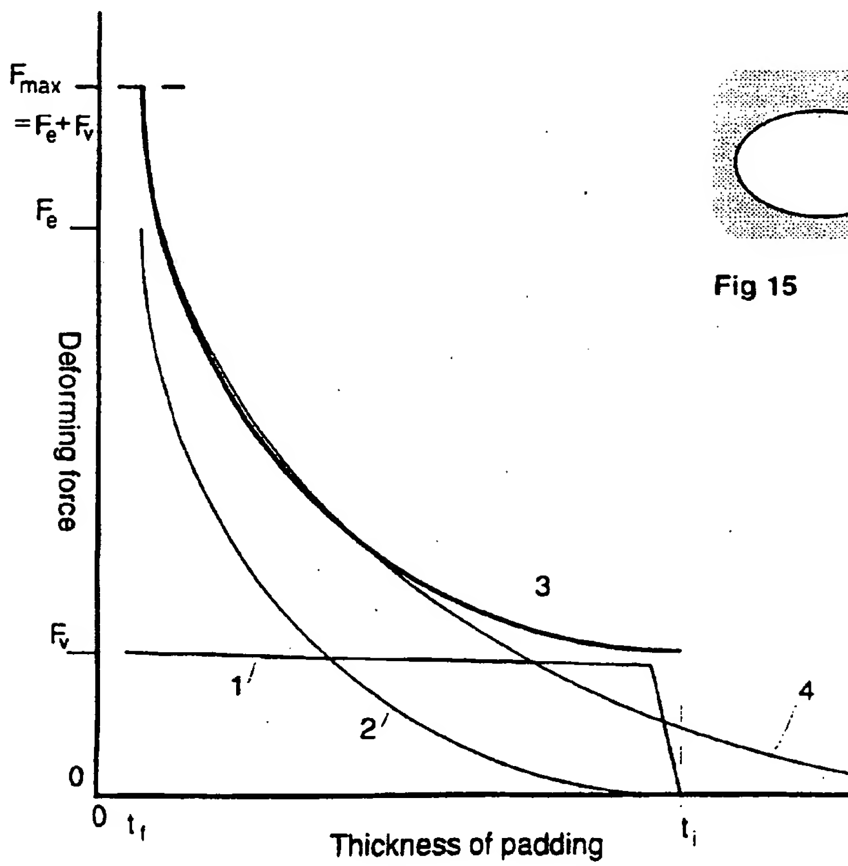

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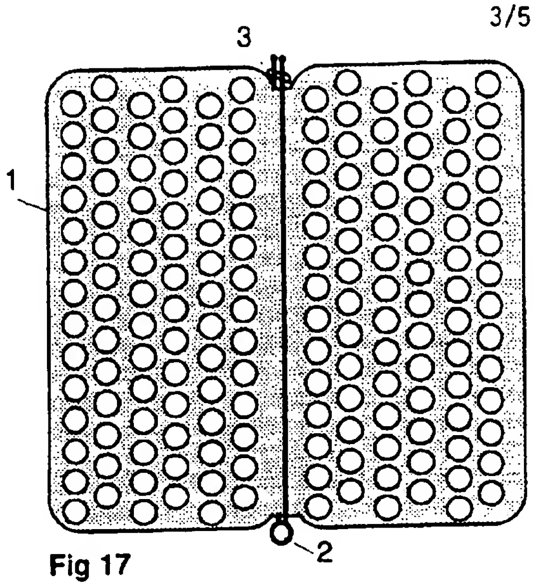
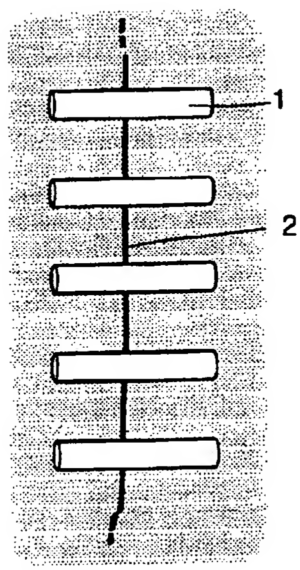


Fig 17



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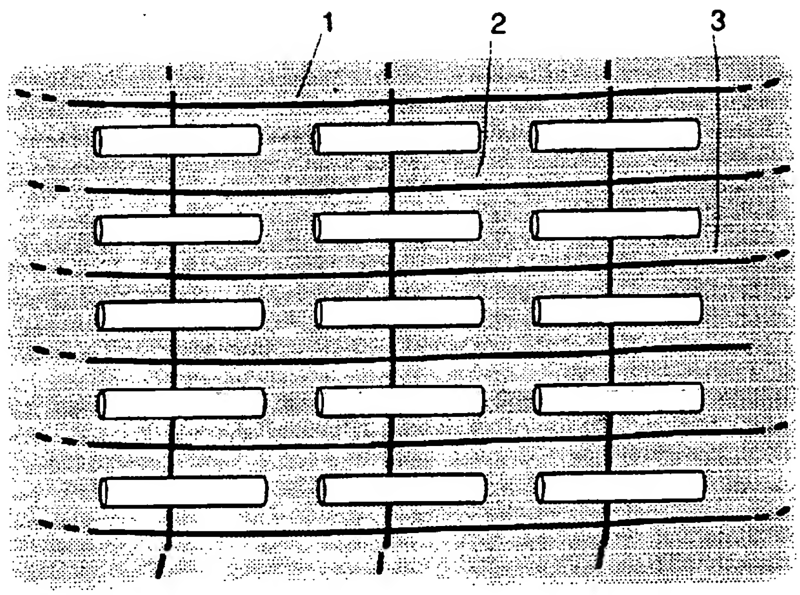

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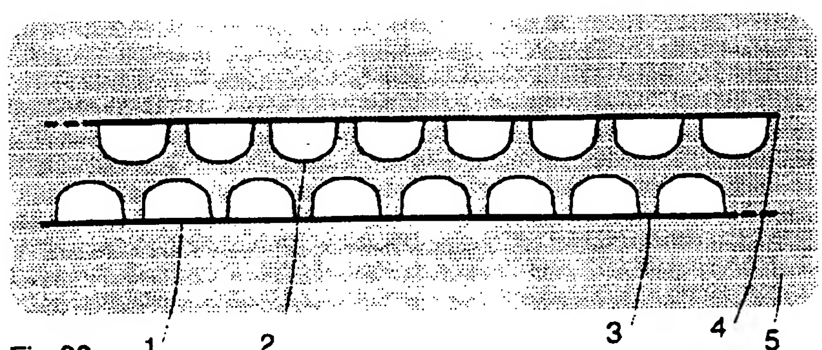

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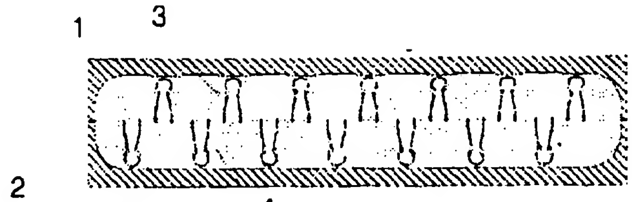

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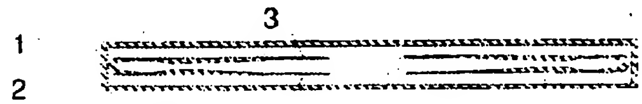

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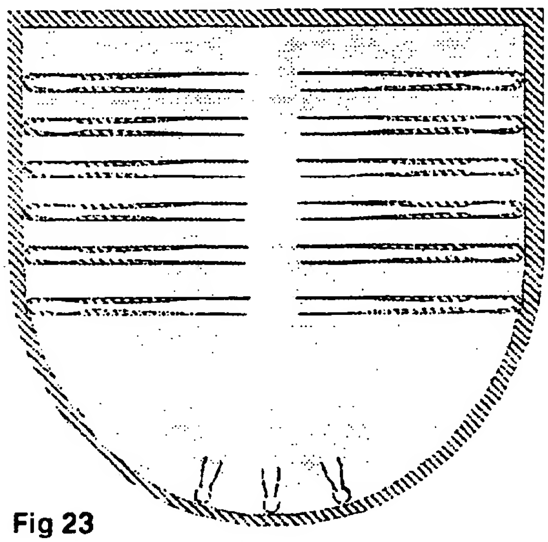

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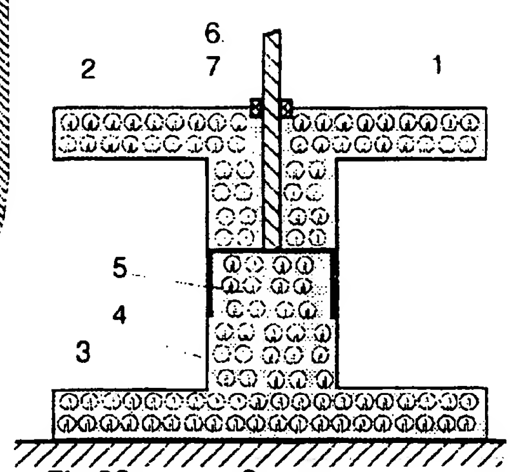

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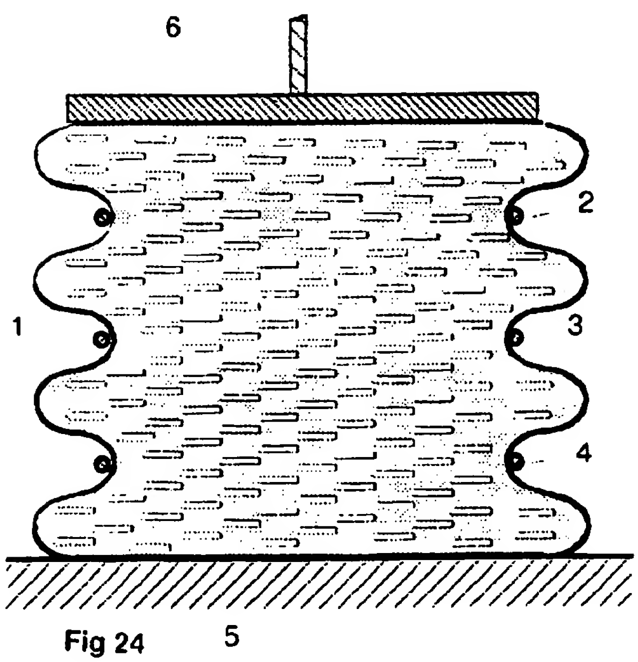

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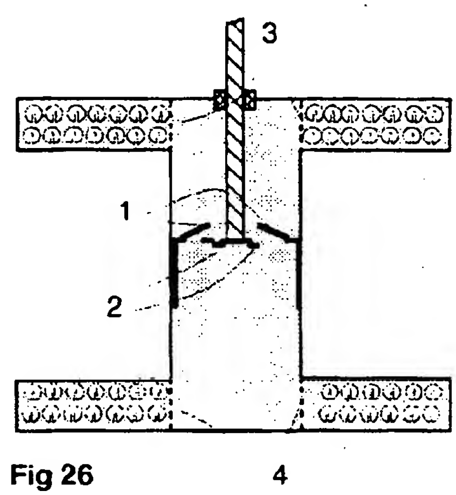

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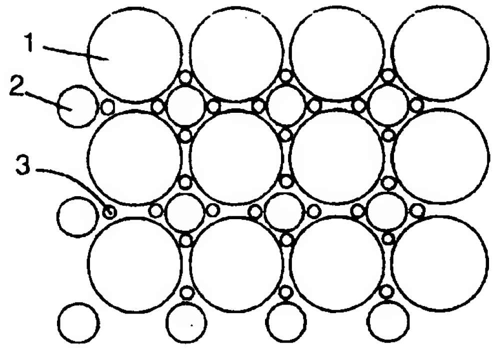

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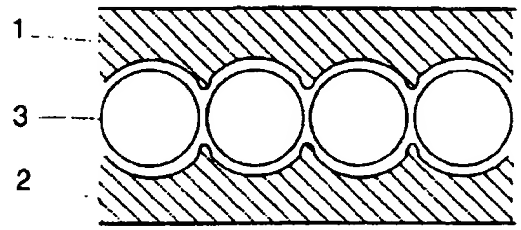

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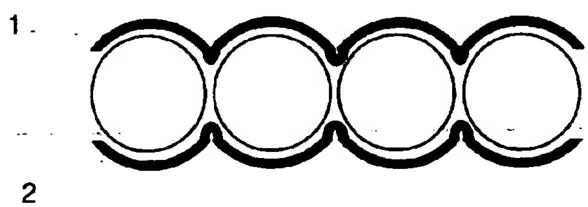

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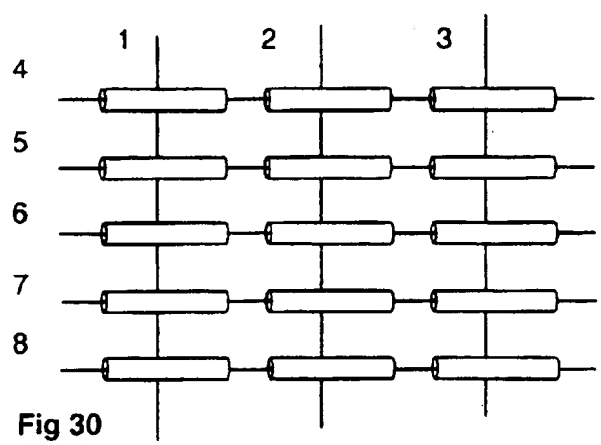

Fig 30